

DYNAMIC BEHAVIOR OF SANDWICH BEAM WITH PIEZOELECTRIC LAYERS

**A THESIS SUBMITTED IN PARTIAL REQUIREMENTS FOR THE
DEGREE OF**

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Contents

Serial No.	Description	Page No.
1	1. Abstract	3-6
2	2. Introduction	7
	2.1 Sandwich Beam.	7-8
	2.2 Behavior Of Sandwich Beam.	8-9
	2.3 Advantages Of Sandwich Beam.	9-10
	2.4 Critical Elements In A structure.	10
3	3. Motivation Of The Present Work	11
4	4. Literature Review	12-16
5	5. Analytical Work	17-28
6	6. Calculations	29
7	7. Conclusion	30
8	8. Scope For Future Work	30
9	9. References	31-34

ABSTRACT

Sandwich beams with composite face sheets and foam core are widely employed as lightweight components in many of the industries that extend from automotive, marine to aerospace applications due to its high bending stiffness and strength combined with low weight factor. Therefore, it is important for us to gain insight about their flexural or bending behaviour under static as well as dynamic loads. Extensive research has been carried out on the flexural behaviour of composite laminates. The flexural and bending behaviour of sandwich structures is quite and obviously different. Several works treating the dynamic flexural behaviour of sandwich beams have also confirmed the marked susceptibility of sandwich structures to damage caused by the impact of low velocity foreign objects. Impacts can certainly damage the face sheets, the core material, and the core face interface. The type of damage found in the faces is similar to that observed after impacts on monolithic composites. However, the damage initiation thresholds and damage area depend on the properties of the core material and the relationship between the properties of the core and those of the face sheets.

Thus we need the FEM simulations of sandwich beams and accurate descriptions of the damage induced by the contact area, and finally we require the modelling of both the face sheets as well as the core.

The researches for new vibration control systems are all about hybrid active–passive control strategies. These were mainly based on simultaneous application of piezoelectric and viscoelastic materials in the same damping treatment. In particular, it was found that, for the last 6 years, these researches have focused on configurations that increase the damping ability of the conventional passive constrained layer damping treatments. Depending on the position of the piezoelectric actuator, the passive and active actions can operate either on their own or simultaneously. In the former configuration, the passive constrained layer and piezoelectric patches are placed away from each other, so that each of them uses independently its own damping mechanism.

The piezoelectric actuator employs the conventional active control mechanism, based on induced in-plane piezoelectric actuation strains; whereas, the passive constrained layer employs its conventional passive damping mechanism, based on vibratory energy dissipation that happens through the transverse shear strains induced in the viscoelastic material by relative in-plane displacements of the constraining layer and base structure.

A sandwich beam was made of laminate faces, with elastic and piezoelectric sub layers, and viscoelastic core. Faces was modeled using the classical laminate theory and the whole beam was modeled using classical sandwich theory. Euler–Bernoulli assumptions were considered for

the laminate faces, whereas those of Timoshenko were retained for the viscoelastic core. The piezoelectric layers were supposed transversely poled and subject to transverse electrical fields. Elastic and viscoelastic layers are assumed to be insulated. All layers are assumed perfectly bonded and in plane stress state.

An electromechanically coupled finite element model was used to handle the active–passive damped multilayer sandwich beams. Classical laminate theory was used to model the multilayer piezoelectric faces, whereas classical sandwich theory was considered for the laminate piezoelectric face, viscoelastic core, laminate piezoelectric face beam, leading to three-layer kinematic description and layer wise material constitutive equations. This has resulted in additional membrane bending coupling terms in electromechanical internal and external forces and translation to rotation coupling terms in inertial forces.

A hybrid active-passive damping mechanism, replacing the elastic constraining layer of a conventional Passive Constrained Layer Damping treatment by a piezoelectric actuator, was used to increase the shear deformation in the viscoelastic material and, thus, the energy dissipation. The electric field was applied perpendicular to the poling direction of the piezoelectric actuators to cause transverse shear deformation of the sandwich beam. Active vibration suppression is achieved using either positive position feedback or strain rate feedback. The control system is implemented in real-time using Matlab/Simulink and a dSPACE digital controller. First, the frequency response of the adaptive beam is investigated by using one shear actuator to excite the beam and the other to control its vibration. Parametric studies are conducted to assess the influence of controller parameters on the frequency response of the system.

Using a proof-mass actuator that was attached to the tip of the cantilever beam in the time domain the effectiveness of the active vibration suppression system was analyzed using a proof-mass actuator which was attached to the tip of the cantilever beam to provide an input of repeatable vibration. Piezoelectric actuators that are used in adaptive structures are thin wafers, which are poled in the thickness direction and bonded to the surfaces of the host structure. An electric field applied in the thickness direction causes the lateral dimensions of the actuators to increase or decrease, thereby forcing the host structure to deform.

A piece of viscoelastic damping material sandwiched between an active piezoelectric layer and the host structure constitutes Active constrained layer (ACL) damping. An Active Constrained configuration will raise the viscoelastic layer damping ability by increasing its shear angle during operation. That is the ACL will enhance the system damping when compared to a structure with traditional passive constrained layers.

Experimental results are presented for an adaptive sandwich cantilever beam that consists of aluminum facings and a core made of two piezoelectric shear actuators and foam. The electric field is applied perpendicular to the poling direction of the piezoelectric actuators to cause transverse shear deformation of the sandwich beam. Active vibration suppression is achieved using positive position feedback. Piezoelectric actuators employed in adaptive structures are usually thin wafers which are poled in the thickness direction and bonded to the surfaces of the host structure.

The application of an electric field in the thickness direction causes the lateral dimensions of the actuators to increase or decrease, thereby forcing the host structure to deform. The actuators are usually placed at the extreme thickness positions of a plate-like structure to achieve the most effective actuation. This subjects them to high longitudinal stresses and may lead to failure, especially when they are made of brittle piezo-ceramics. To alleviate these problems several researchers have investigated adaptive sandwich structures consisting of axially-poled piezoelectric actuators.

The work to do is modeling of sandwich beam for active vibration control analysis on working software Ansys. The inputs for the sandwich beam are varied materials with different properties in different directions. The beam is isotropic in nature. The properties of materials include Young's modulus, Poisson Ratio, and Density of material. The excitation is given in intervals with varying frequency values within permissible limit. The material type used are coupled field, Solid , Visco-solid. the inputs are given in Material Models in Preprocessor and Material Properties.

The modeling is done for sandwich beam with create volume option with dimensions known in the software. Meshing is done for the whole volume for nodal points of force application. Force has to be applied in the nodal point which has maximum displacement. The vibration given at that nodal point is to be suppressed with active vibration control mechanism. Solution after load application is solved in Ansys with FloatRun option for viewing analytical solution regarding control mechanism.

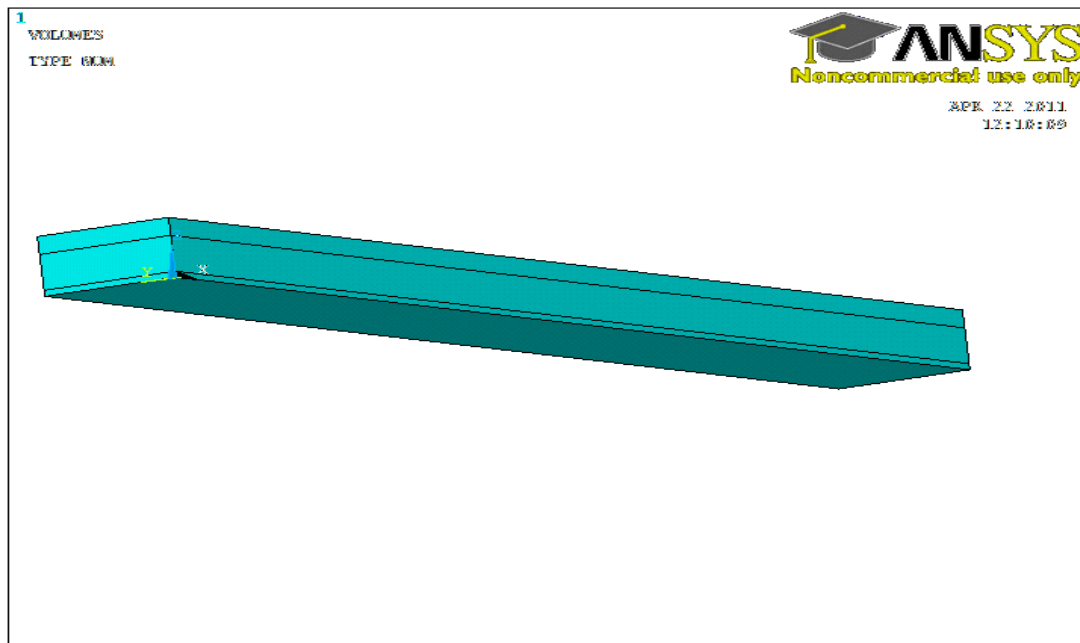


Fig 1(a). Schematic Diagram Of A Sandwich Beam

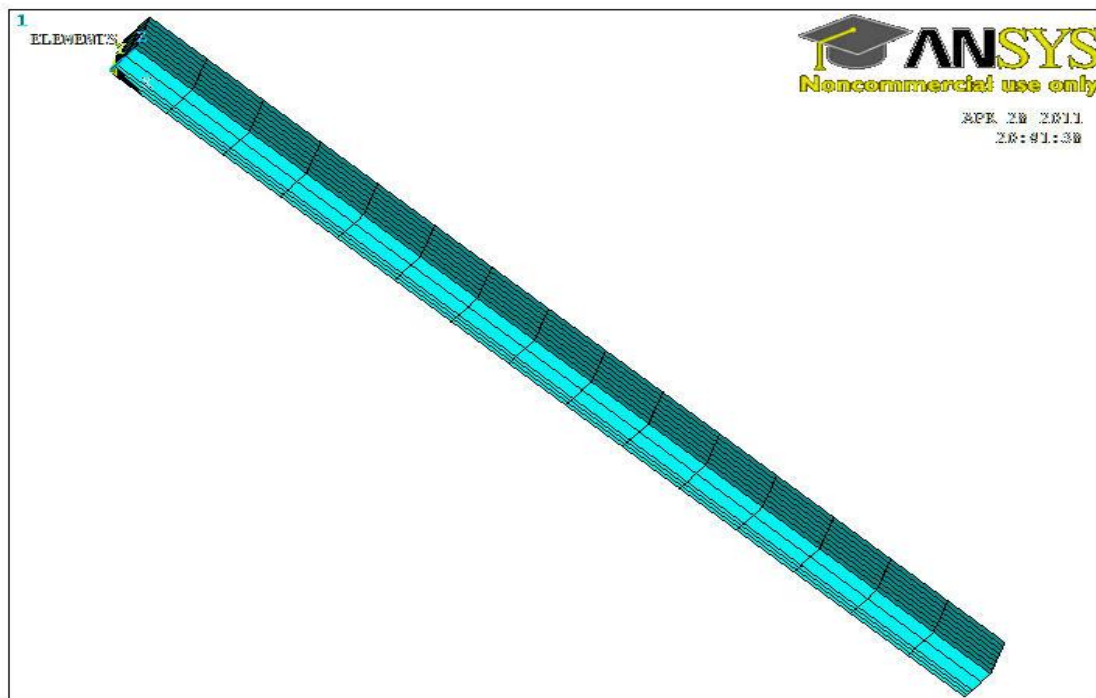


Fig 1(b). Schematic Diagram Of A Meshed Sandwich Beam

2. INTRODUCTION

2.1 SANDWICH BEAM

Sandwich beam is nothing but a composite beam in which a viscoelastic layer is sandwiched between two elastic layers.

According to the sandwich theory, it describes the behavior of a beam which consists of three layers - two face sheets and one core that is used in between the two face sheets. The most commonly sandwich theory that is applied is a linear and is an extension of first order beam theory. Linear sandwich theory is of utmost importance for the design and analysis of sandwich panels, which are of use in building construction, vehicle construction, airplane construction and refrigeration engineering.

The sandwich panels are a special class of composite materials that is fabricated by attaching two thin but stiff skins to a lightweight but thick core. The core material is of a low strength material, but higher the thickness higher will be the bending stiffness with overall low density.

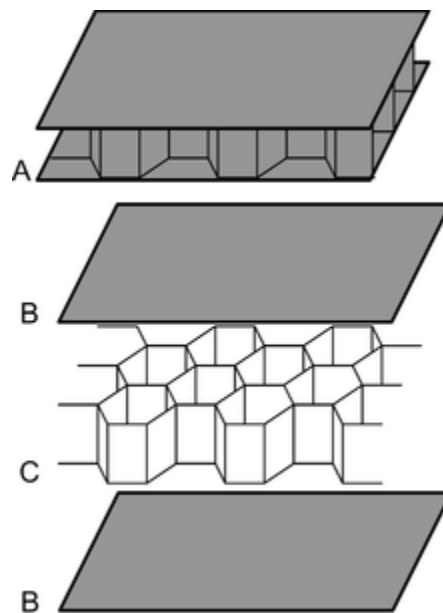


Fig 2. Assembled Composite Sandwich

Diagram of an assembled composite sandwich (A), and its constituent face sheets or skins (B) and honeycomb core (C).

Open and closed cell structured foam, polystyrene, balsa wood and honeycomb are commonly employed as core materials. Glass or carbon fiber reinforced laminates are widely as skin materials. Sheet metal is also employed as skin materials.

Metal composite material (MCM) is a type of sandwich structure formed by the application of two thin skins of metal bonded to a plastic core in a continuous process under controlled pressure, heat, and tension.

Recycled paper is also now being employed over a closed-cell recycled kraft honeycomb core, which helps in creating a lightweight, strong and fully repulpable composite board. This material is being employed for applications including point-of-purchase displays, recyclable office furniture, exhibition stands and wall dividers.

To fix different panels, among other solutions, are normally use a transition zone, which is a gradual reduction of the core height, until the two fiber skins are in touch. In this place, the fixation can be made by means of bolts, rivets, adhesive or can be selected from different kinds of material available.

The strength of the composite material is largely dependent on two factors:

1. The outer skins:

If the sandwich is given support on both sides, and is then stressed by means of a force in the middle of the beam, then the shear forces from the bending moment will be introduced within the material. The shear forces results in the bottom skin being in tension and the top skin being in compression. The core material spaces those two skins apart. The thicker the core material, then stronger is the composite. This principle works for an I-beam too.

2. The interface between the core and the skin:

As the shear stresses in the composite material changes rapidly between the core and the skin, the adhesive layer also sees some degree of shear force. If the adhesive bond between the two layers is too weak, the most probable result will be de lamination in those sheets.

2.2 Behavior of Sandwich Beam:

The behavior of a beam with sandwich cross-section under a load will differ from a beam with a constant elastic cross section. If the radius of curvature during bending is found to be small compared to the thickness of a sandwich beam and the strains in the component materials are small, the deformation of a sandwich composite beam can be separated into two parts :

1. Deformations that occurs due to bending moments or bending deformation, and
2. Deformations that occurs due to transverse forces, also called shear deformation.

For sandwich beam, plate, and shell theories the reference stress state is one of zero stress. But, during curing, there is a difference of temperature between the face-sheets because of the thermal separation by the core material.

The face-sheets with different linear expansions are coupled. Due to temperature difference it can lead to the bending of the sandwich beam having the warmer face-sheet compared to the other face sheet. Residual stresses can develop during the manufacturing process if the bending is constrained.

The superposition of a reference stress state on the solutions provided by sandwich theory is possible when the problem is linear. However, when large elastic deformations and rotations are expected, the initial stress state has to be incorporated directly into the sandwich theory.

2.3 Advantages of Sandwich Beam:

1. Sandwich cross sections are usually composite. They consist of a low to moderate stiffness core which is then connected with two firm exterior face-sheets. The composite has considerable higher shear stiffness to weight ratio compared to an equivalent beam made of only the core material or the face-sheet material. The composite also has a very high tensile strength to weight ratio.
2. High bending stiffness to weight ratio for the composite is achieved because of the high stiffness of the face-sheet.

2.3.1 Piezoelectric materials:

1. Piezoelectric materials have the ability to generate electric potential in response to applied mechanical stress.
2. This property is exhibited by certain materials like ceramics & some crystals.
3. The piezoelectric effects can be seen as transfer between electrical and mechanical energy.
4. Such transfers can only occur if the material is composed of charged particles and can be polarized.
5. For a material to exhibit an anisotropic property such as piezoelectricity, its crystal structure must have no centre of symmetry.

2.3.2 Piezoelectric Layered Sandwich Beams:

Active control of smart structures depends on the magnitude of electric potential difference for a given mechanical stress. This subsequently depends on the piezoelectric stress/strain constants.

The existing monolithic piezoelectric materials being used in beams possess low control authority as their piezoelectric stress/strain constants are of small magnitude. Because, tailoring of these properties may improve the damping characteristics of the smart structures. These beams show improved mechanical performance, electromechanical coupling characteristics, and acoustic impedance matching with the surrounding medium over the piezoelectric material alone.

2.4 Critical Elements in a structure:

There are two important components in a structure:

1. Actuators
2. Sensors

2.4.1 Actuators:

Actuator is generally the reverse of sensor. It converts electrical inputs to physical (thermal, mechanical, etc) outputs. The ideal mechanical actuator would directly convert electrical input into strain or displacement in the host structure. The principal actuating mechanism of actuators is referred to as actuation strain.

2.4.2 Sensors:

Sensors are mechatronics devices that can convert analogue physical values into electrical impulses thus informing of their magnitude. The ideal sensor for structures converts strain or displacement directly into electrical output. The primary functional requirement of such sensors is their sensitivity to strain and displacement.

3. Motivation Of The Present Work

Sandwich beams which are the answer to many structural problems demanding self control and flexible characteristics involving mechanical and thermal stresses. The technological implications of this class of beams are immense, as they are especially useful in remote operations, expensive space operations subjected to extreme thermo-mechanical loadings, aerospace skins, protective shields, components in reactor vessels, machine tools, and medical applications, to name only a few. As the advent of steel changed the last century, similarly these beams which will revolutionize the 21st century.

The beams have characteristics such as thermo-electro-mechanical coupling, functionality, intelligence, and gradation at micro and nano scales. The reliability and integrity of these systems are the main challenges before us. They can be customized to operate under varying conditions covering the whole spectrum of electro-thermo-mechanical conditions. The conditions can vary across a wide range of temperature, magnetic & electric fields, pressure and mechanical load, and/or a combination of two or many. Experimental investigations of both these systems & beams although possible, are prohibitively expensive, and therefore must be complemented with simulations and theoretical analyses.

4. LITERATURE REVIEW

A.Benjeddou in ‘Advances In Piezoelectric Finite Element Modeling Of Adaptive Structural Elements’ proposed that earlier piezoelectric materials were of great interest for finite element modeling, but interests have been shifted to smart structures and modeling of the same for advanced applications. These smart structure includes composite plates, sandwich beams, shells. The trends and advances in these structures are determined by the electrical properties and elemental characteristics such as shape, independent variables and degree of freedom. For finite element formulation, the basic equation governing the electrostatic behavior of the piezoelectric element is assumed. Modeling of intelligent structures is done for finite analysis followed by conventional actuation method is applied. The important feature of the piezoelectric material to finite element modeling is its electromechanical coupling and electric charge is distributed on both top and bottom sides of the piezoelectric patches. The electromechanical coupling and surface characteristics can be handled through three-dimensional finite element modeling with modified degree of freedoms. Shear actuator mechanism is used for thin plates and sandwich beams, which makes it high efficient and better performance consideration. Finite element development took place with three-dimensional elements with electric as well as mechanical degree of freedoms for formulating electromechanical coupling and surface characteristics of the sample. Two-dimensional elements were formulated for thin sheets and composite plates with electric DOF.

Brian.P.Baillargeon in ‘Active Vibration Suppression of Sandwich Beams Using Piezoelectric Shear Actuators’ proposed that piezoelectric material has a capacity of producing self-actuated voltage, when stress is being applied on it. When load is applied on the cantilever beam, sandwiched with piezoelectric and core material, it causes transverse shear deformation. Active vibration suppression is achieved either through strain rate feedback or positive position feedback. Actuators basically serve for two types of purposes. It helps in excitation of the beam and controlling of the vibrations. Piezoelectric actuators are actually bonded to host structures and electric field applied to the bonded sheet causes change in lateral dimensions and hence deformation in host structure. The actuators used in this case for deformation in piezoelectric material with the help of application of electric field are called piezoelectric extension actuators. These types of actuators are much efficient and brittle, which increases its failure rate. To overcome this problem, adaptive sandwich structures consisting of the axially poled piezoelectric actuators have been proposed. The axially poled piezoelectric actuator when sandwiched between viscoelastic layers is of optimum strength to overcome transverse deflection within permissible limits.

Jingjun Zhang in 'Active Vibration Control of Flexible Structures Using Piezoelectric Materials' Proposed that Piezoelectric ceramics can be used in wide variety of applications like from active vibration control to nano-positioning technology. Piezoelectric ceramics are of greater concern because of its mechanical simplicity, light weight, low volume, conversion between electrical energy to mechanical energy etc. These days, we can see undesirable vibrations are produced during an operation, which causes failure of the system. These can be reduced with the help of feedback control mechanism. There are two types of feedback mechanisms to damp the undesired vibrations. Positive position feedback is applied by providing structural position coordinate directly to compensator. Strain rate feedback mechanism is used for active damping of flexible structures where lateral deformation occurs with load application. Here steel acts as a core material and piezoelectric patches acts as sensor as well as actuators. Actuators actuates the flexible structure with varied frequency and sensor senses the vibration, control system sends signals to sensor with equal and opposing voltage to damp the vibrations.

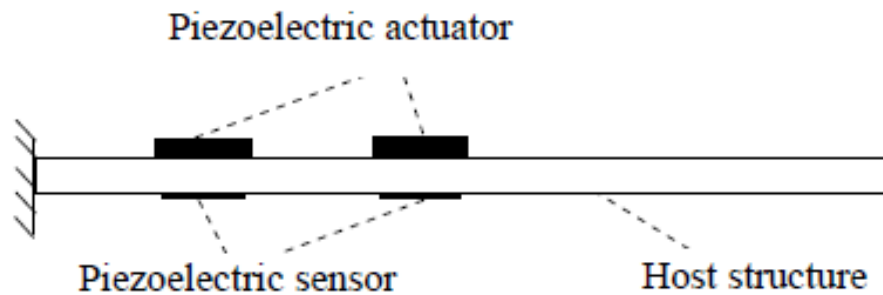


Fig 3. An assembled sandwich beam with actuators and sensors on board.

Anna Markidou in 'Soft-materials elastic and shear module measurement using piezoelectric cantilevers' has proposed a method for finding shear and elastic properties of the soft materials. Sensors made up of soft material elastic modulus and shear modulus, are used in piezoelectric cantilever for actuation and damping purpose. Applying electric field in the direction of thickness causes deformation generating axial displacement or force. Elastic modulus depends on axial displacement and axial displacement can be measured with proper geometry of the cantilever beam. The elastic and shear modulus of soft tissues like rubber material and gelatin can be measured with the help of piezoelectric cantilever beam of lower dimensions. The main purpose of this paper is to develop a sensor which can measure elastic and shear properties of the soft materials with sensor operating in few micron levels. With experiments, we can calculate

spring constant K , by placing different weights at cantilever tip. Shear tests and compression tests were carried out to find elastic and shear properties of the sample.

W.H.Liao in 'on the analysis of viscoelastic materials for active constrained layer damping treatments, 1997' proposed that viscoelastic material influence the functioning of active as well as passive damping. The beam used here is viscoelastic layer sandwiched between active piezoelectric layer and host structure. During the experimentation, it has been found out that active piezoelectric action in Active Constrained Layer configuration will enhance the viscoelastic layer damping by increasing its shear angle. It is desirable that viscoelastic material has high loss factor to obtain good passive damping abilities and active passive hybrid actions. One should select viscoelastic material with high shear modulus high active gains for lowered rate of vibrations. Based on the experiment results, it will be desirable if one can develop means to reduce the viscoelastic effect on active vibration control, while retaining the passive damping ability in the Active Constrained Layer. This could increase the design space for viscoelastic selections and enhance the ACL overall.

Raja in 'Modelling, Simulation and Validation for Active Vibration Control of Smart Sandwich Beam with Piezoelectric Actuation, 2002' proposed a theory on modelling and active vibration control of smart structures with piezoelectric actuation. The sandwich beam is a composite of piezoelectric and piezoceramic materials for intelligent behaviour response. For correct simulation, finite element procedures have to be applied in modelling of sandwich beams with distributed actuated and sensing capabilities. For actuation, an elastic core is sandwiched between two transversely polarised piezoelectric layers, whereas for shear actuation, an axially polarised piezoelectric core is sandwiched between two composite faces.

Zeki kirali in 'Active control of residual vibration of a cantilever smart beam, 2007' has proposed a theory paper to control the residual vibrations of clamped-free beam subjected to a load. Vibrations are considered as undesirable output due to waste of energy, precision loss, noise etc., and should be kept under control. Two laser displacement sensors are used to figure out the dynamic response of the beam during load application. Dynamic response of the beam is calculated by finite element modelling for designing a control mechanism. In this experimental study, piezoelectric actuators are used for active vibration control and displacement feedback mechanism is employed. Modelling is done by finite element procedures and simulation results are done in analysis software ANSYS. Author has concluded that residual vibrations of the smart beam are suppressed to greater extent through active vibration control and displacement

feedback. The design of active vibration control of more complex structures can be achieved with the finite element packages, which enable us to use active elements.

D. A. van den Ende in 'Piezoelectric and mechanical properties of novel composites of PZT and a liquid crystalline thermosetting resin, 2007' has proposed a theory based on piezoelectric and mechanical properties of PZT and liquid crystalline resin (LCR) for actuation purpose. The piezoelectric properties of polymer are greatly influenced by temperature. The polymers show excellent process ability in high temperatures. Good chemical and thermal resistance of polymer, makes it better material for sensor applications at high temperatures. Author concluded that PZT-LCR composite have high piezoelectric voltage, which is a better quality for sensor applications. Dielectric and piezoelectric behavior of thermosetting resin have been described. These sensors can be used in automobile and aerospace applications, where elevated temperatures are employed. A maximum operating temperature was observed at which, piezoelectric attributes are found to be deteriorated.

Chih-Liang Chu in 'Active vibration control of flexible beam mounted on elastic base, 2006' investigated the active vibration control of flexible beam which is analyzed through finite element modeling. Shearing deformation and inertia is included in experiment calculation. The controller system in the process works on the principle of suppression of excessive vibration during base excitation, thereby improving dynamic characteristics of system. In industries, the heavy machines during operation are subjected to undesirable vibrations which should be cutoff for high precision outputs. These vibrations are suppressed which control strategy employed. Piezoelectric vibrations and optical sensors were used to perform active vibration control to improve measurement accuracy. Independent modal space control (IMSC) mechanism was employed because this method has a capability to reduce vibration to each and every mode and feedback is applied to every mode, which suppresses vibrations to greater extent. The basic principle of modal space control method is to transform the coupled system dynamic equations into the decoupled modal space, and thereafter apply a process of feedback control to each decoupled mode. Optimum independent modal space control is found and numerical simulation is done during experiments. Author has concluded that Timoshenko theory has been used to develop beam, which is good agreement with results in ANSYS finite element software. In conclusion, the application ensures a superior dynamic performance of a flexible beam mounted on an elastic base.

C.MeI in 'Hybrid wave/mode active control of bending vibrations in beams based on advanced Timoshenko theory,2008' studied active vibration control in beams based on Timoshenko theory. Both mode and wave theory have been combined to improve the performance of the

vibration control. In the proposed hybrid control, wave control is first at one or more points in the structure which absorb vibration energy especially during high frequencies. Modal control is applied for accuracy and robustness of the system. In modal active vibration control, the objective is to control the characteristics of damping factors, natural frequencies or mode shapes. At high frequencies, rotary inertia and shear distortion are taken into consideration. In proposed hybrid approach, two control strategies are employed, one is to absorb vibration energy and another control system is to provide damping to the system. Author has concluded that hybrid approach, which includes both wave as well as modal theory, has an advantage of absorbing vibrations at higher frequency and damping is provided with higher accuracy. The hybrid approach exhibits better active vibration control performance than the cases with either modal or wave control individually.

C.M.A.Vasques in ‘active vibration control of smart piezoelectric beams’ proposed a theory on vibration control through smart beams. A one-dimensional finite element of a three-layered smart beam with two piezoelectric surface layers and metallic core is made composite. The two piezoelectric layers acts as sensor for sensing the amount of displacement and actuator for actuating vibrations with low frequency. A partial layer wise theory and electro-mechanical theory is considered for control mechanism. The main aim of the paper is to reduce vibration of mechanical system by systems structural response. The ability of piezoelectric to produce electric charge (actuating voltage) proportional to the external force applied, is the main characteristics for most of the sensors manufacturing with PZT material. Author studied analysis of active vibration control of a cantilever aluminum beam with piezoelectric patches acting as sensor and actuator. Smart structures have excellent characteristics for damping purpose with low weight applications.

4. ANALYTICAL WORK

After designing of Cantilever Beam in Ansys design software, with specific material properties, analysis is done by applying varying loads (-10N, -50N, -100N, -1000N & -3000N) on the meshed node of the beam to study the stress-strain distribution along the cantilever beam. After analysis procedure, Results are found out in the form of Stress-Strain graphs are plotted for different loads.

Stress Analysis of Cantilever Beam with 10N Force applied in Negative Z direction:

Total No of Nodes: 2936

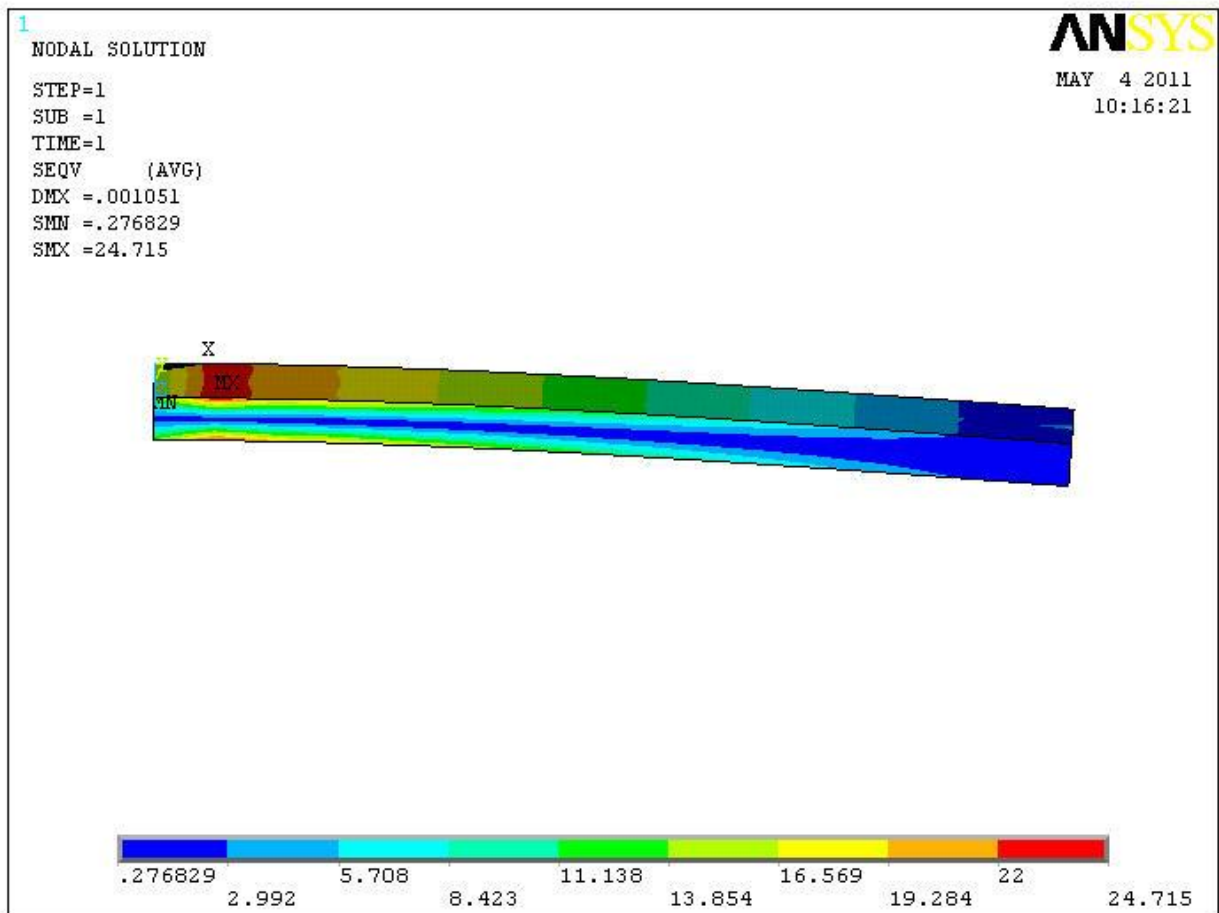
Load Applied: Node 2585

Maximum Stress: Node 243

Minimum Stress: Node 1502

Maximum Strain: Node 243

Minimum Strain: Node 1287



Stress-Strain relationship for 10 N Load applied in the negative Z direction.

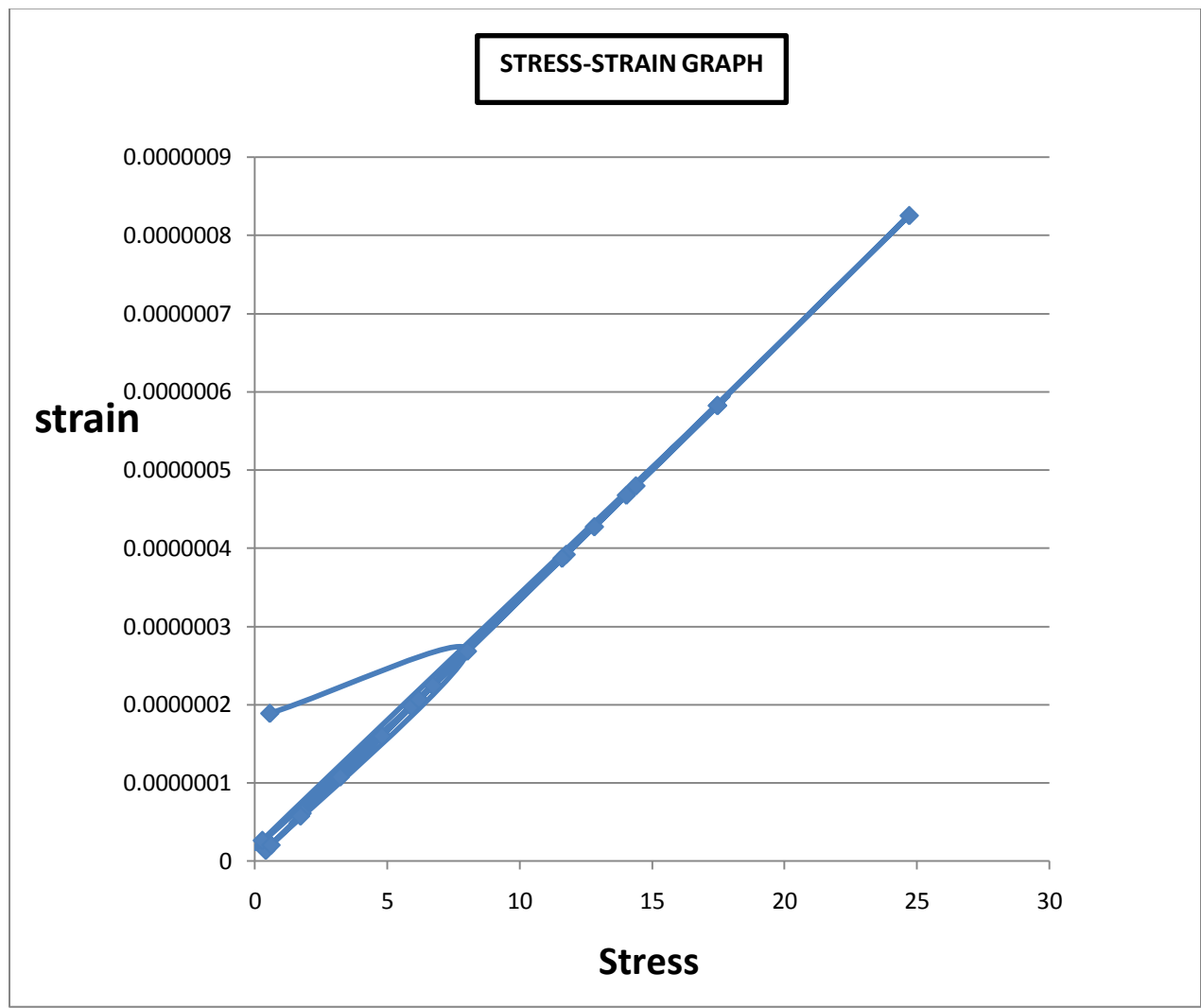
The stress-strain curve is a relation between stress, which is measured with load applied on the beam and strain, derived from measuring the deflection in the beam. Hook's Law relates these parameters within elastic limit.

Maximum Stress: 24.715 N/mm²

Maximum Strain: 0.825E-06

Minimum Stress: 0.2768 N/mm²

Minimum Strain: 0.1361E-07



Stress Analysis of Cantilever Beam with 50N Force along Negative Z axis direction

Total No of Nodes:2936

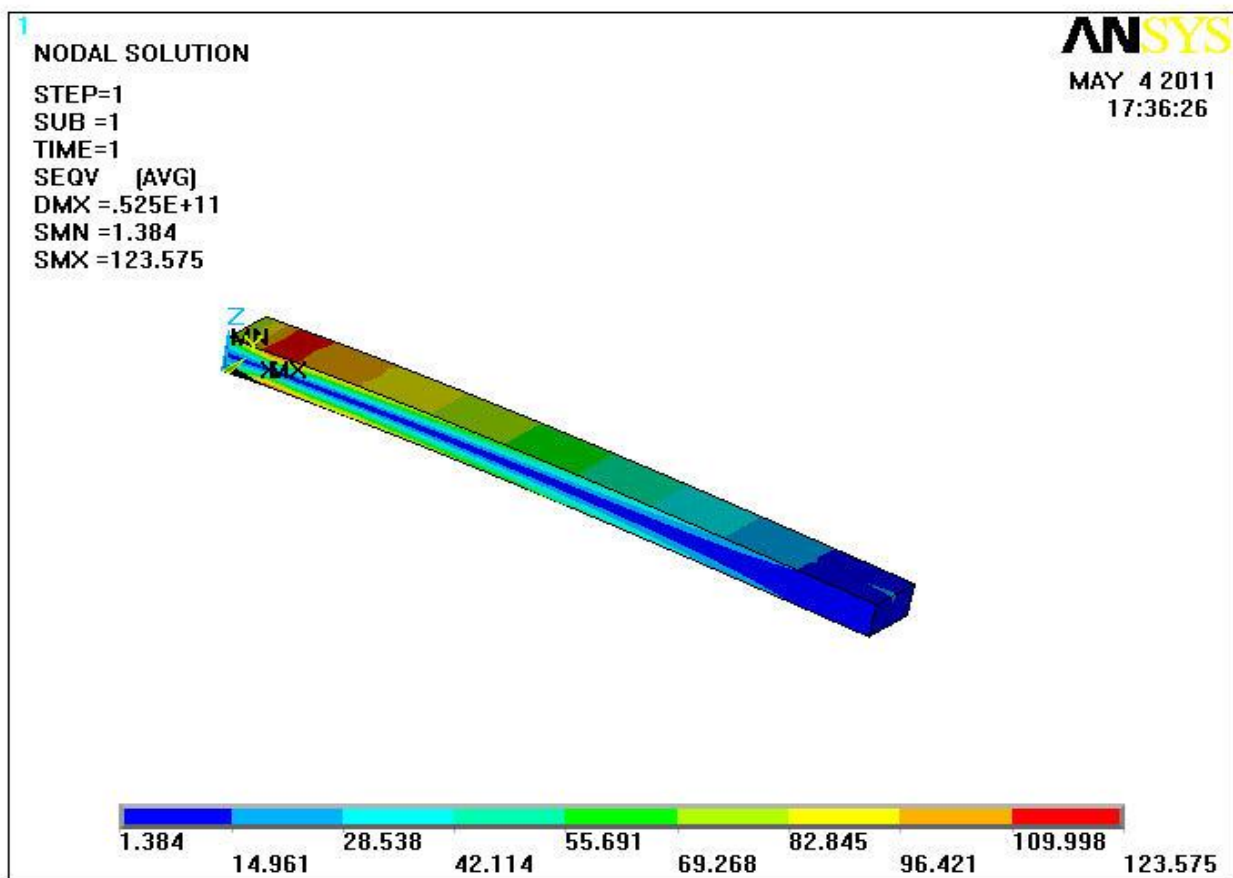
Load Applied: Node 2585

Maximum Stress: Node 243

Minimum Stress: Node 1502

Maximum Strain: Node 243

Minimum Strain: Node 1290



Stress Analysis of Cantilever Beam with 100N Force in Negative Z direction.

Total No of Nodes: 2936

Load Applied: Node 2585

Maximum Stress: Node 243

Minimum Stress: Node 1502

Maximum Stress: 247.15 N/mm²

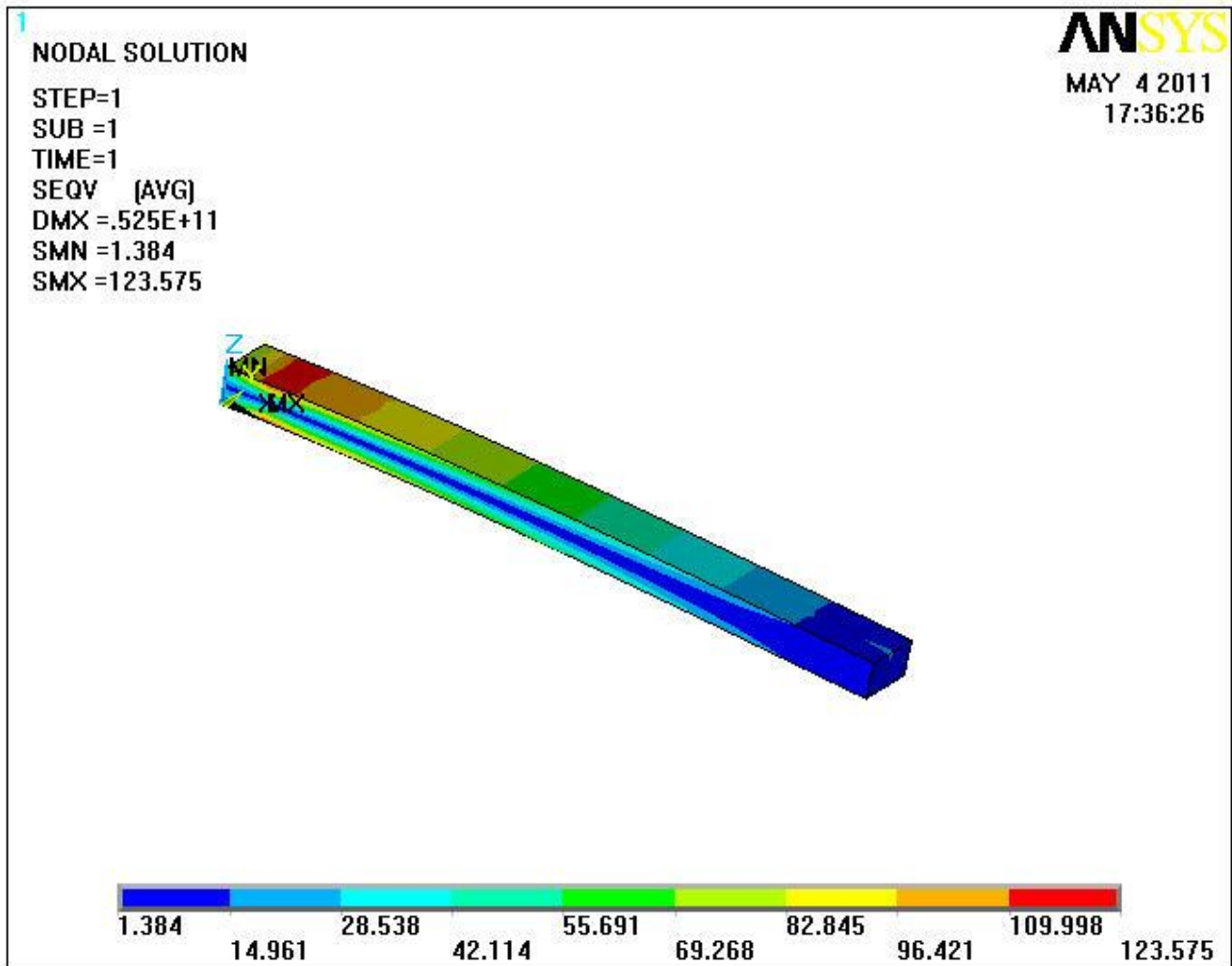
Maximum Strain: 3.25E-05

Maximum Strain: Node 243

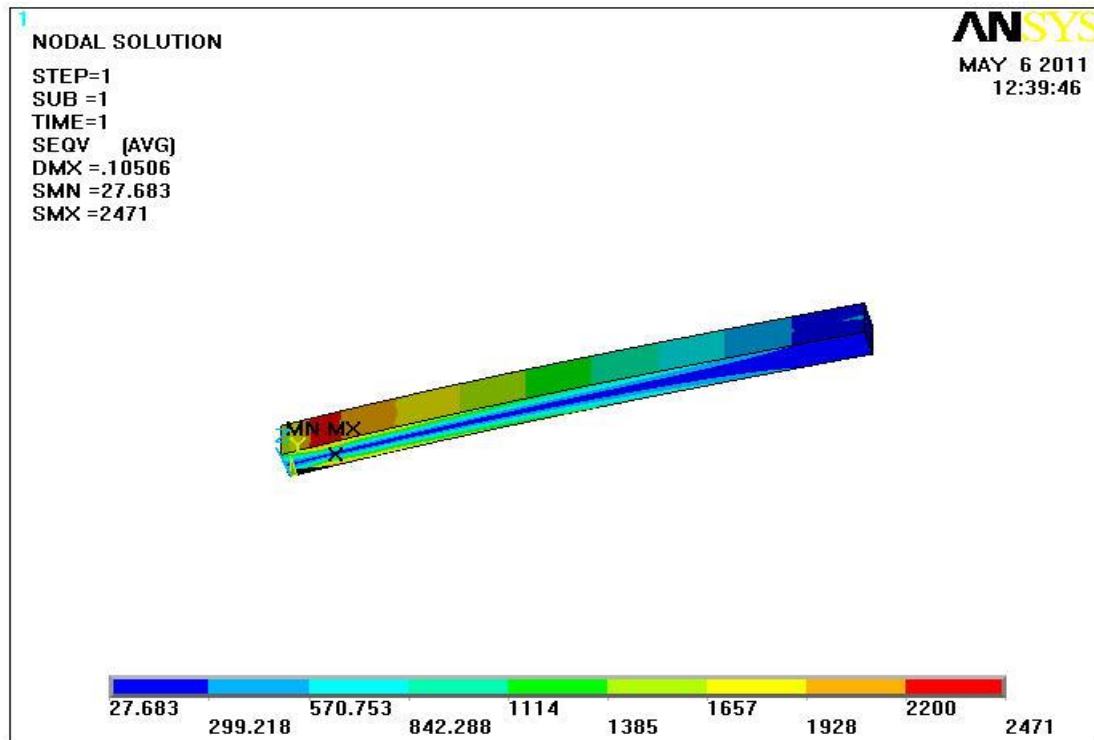
Minimum Strain: Node 1290

Minimum Stress: 2.7683 N/mm²

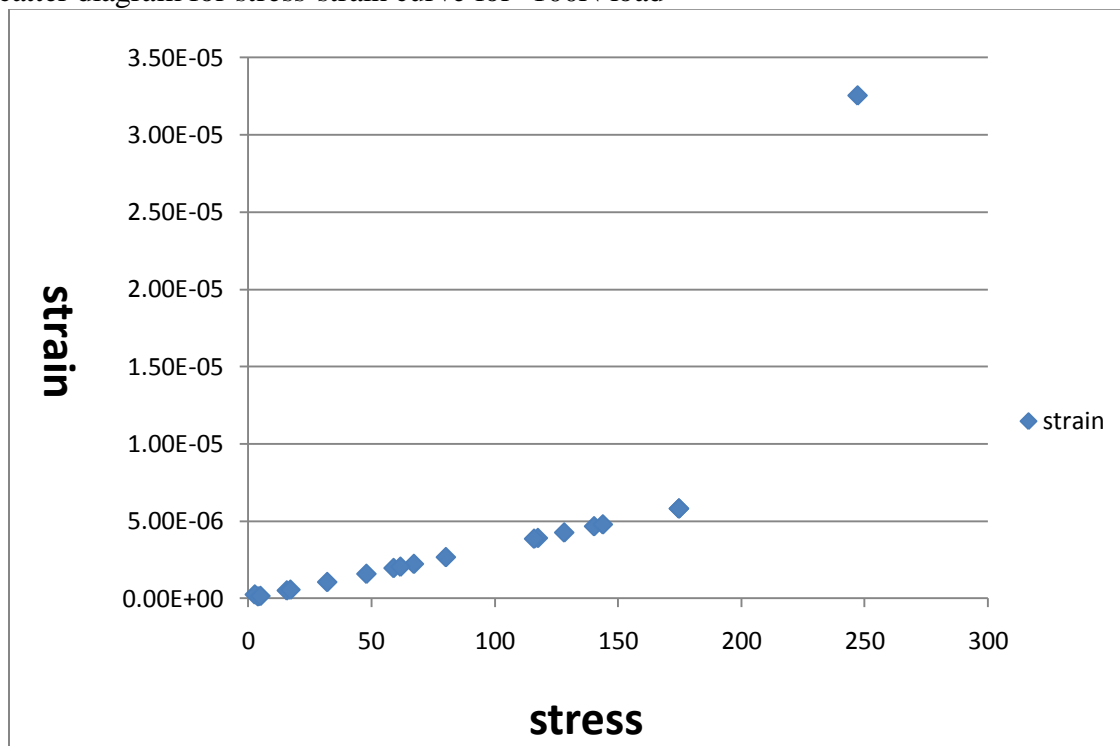
Minimum Strain: 1.36E-07



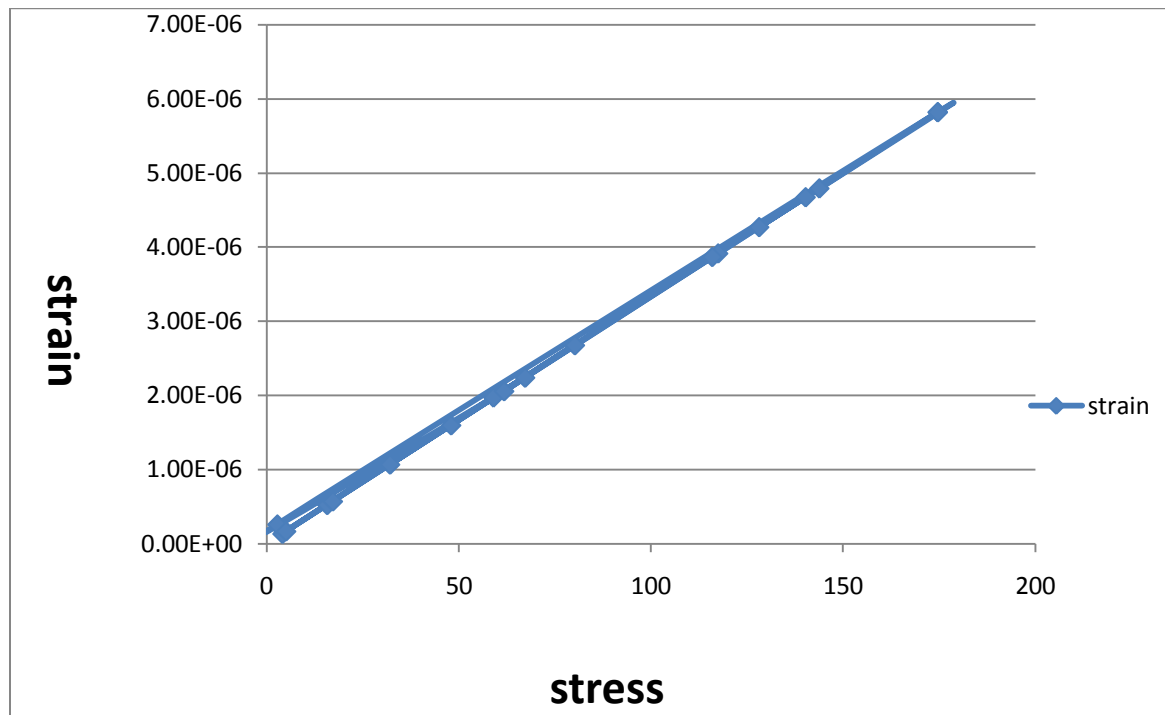
Strain Analysis of Cantilever Beam with 100N Force in Negative Z direction.



1) Scatter diagram for stress-strain curve for -100N load



2) Stress-strain curve for 100N load applied in Negative Z direction



Stress Analysis of Cantilever Beam with 1000N Force in Negative Z direction.

Total No of Nodes: 2936

Load Applied: Node 2585

Maximum Stress: Node 243

Minimum Stress: Node 1502

Maximum Stress: 2471.5 N/mm²

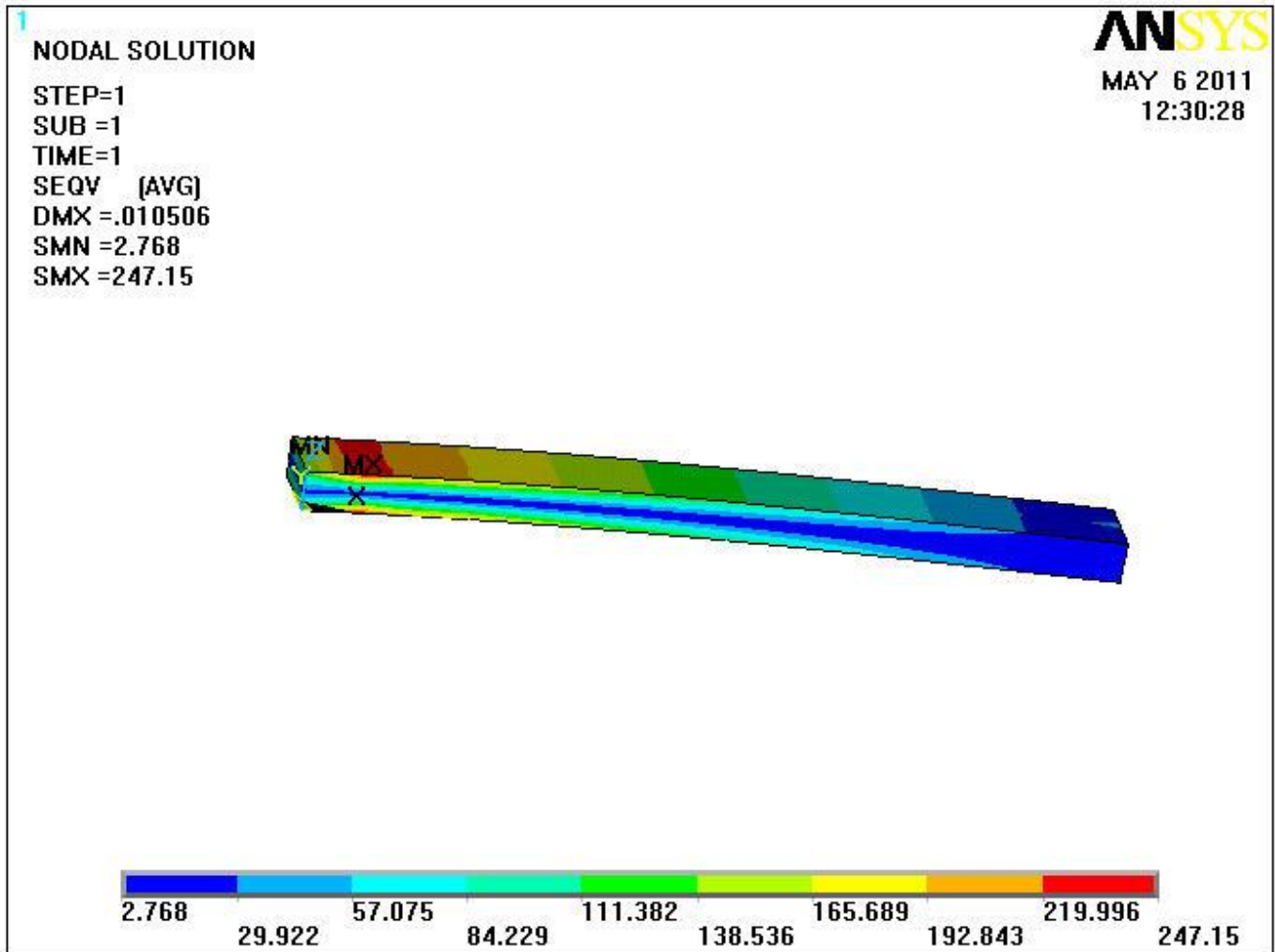
Maximum Strain: Node 243

Minimum Strain: Node 1290

Maximum Strain: 8.25E-05

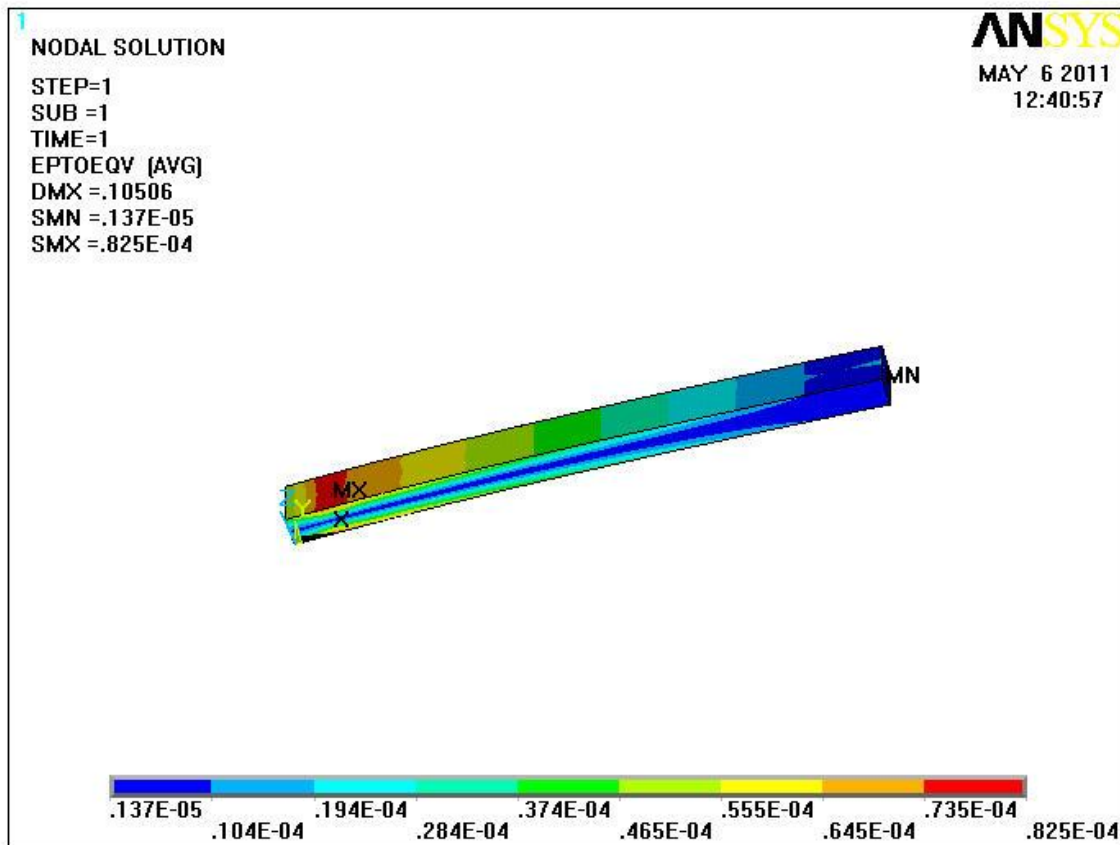
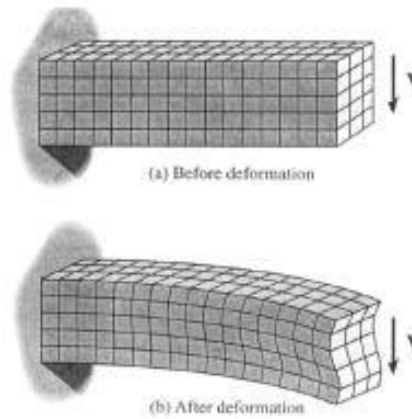
Minimum Stress: 27.683 N/mm²

Minimum Strain: 1.36E-06



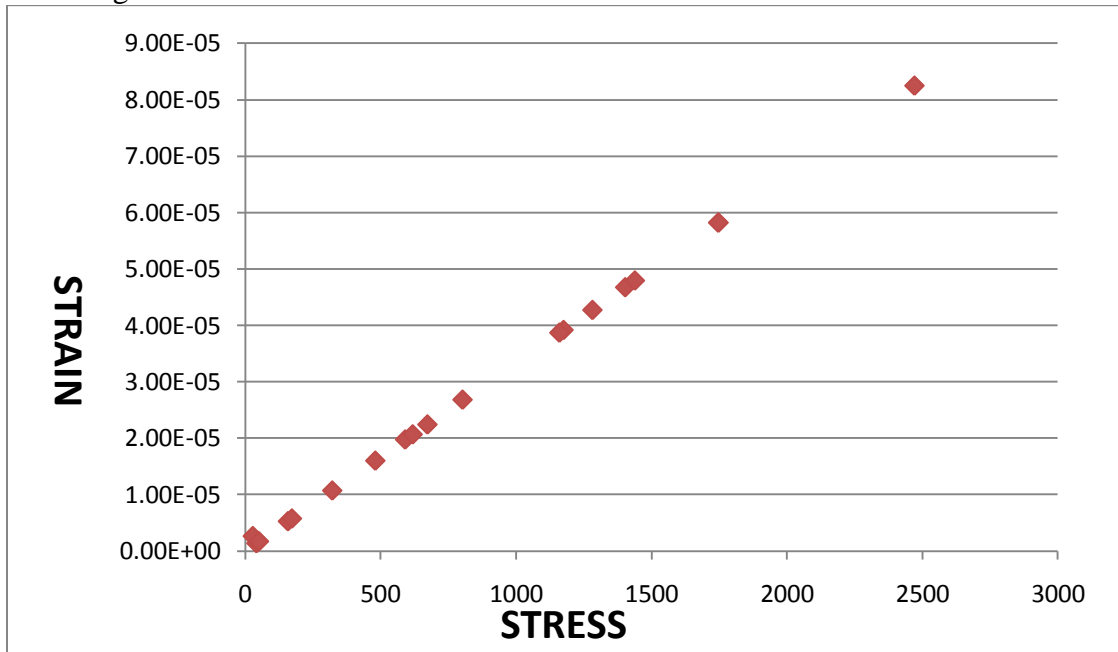
Strain Analysis of Cantilever Beam with 1000N Force in Negative Z direction.

The intensity of strain distributed along the beam is shown in figure with different colors showing variation of strain. With red color being the maximum strain produced area and navy blue indicating minimum strain affected area. Strain is derived from measuring the change in deformation of the sample. Below figure shows the deformation before and after load application.

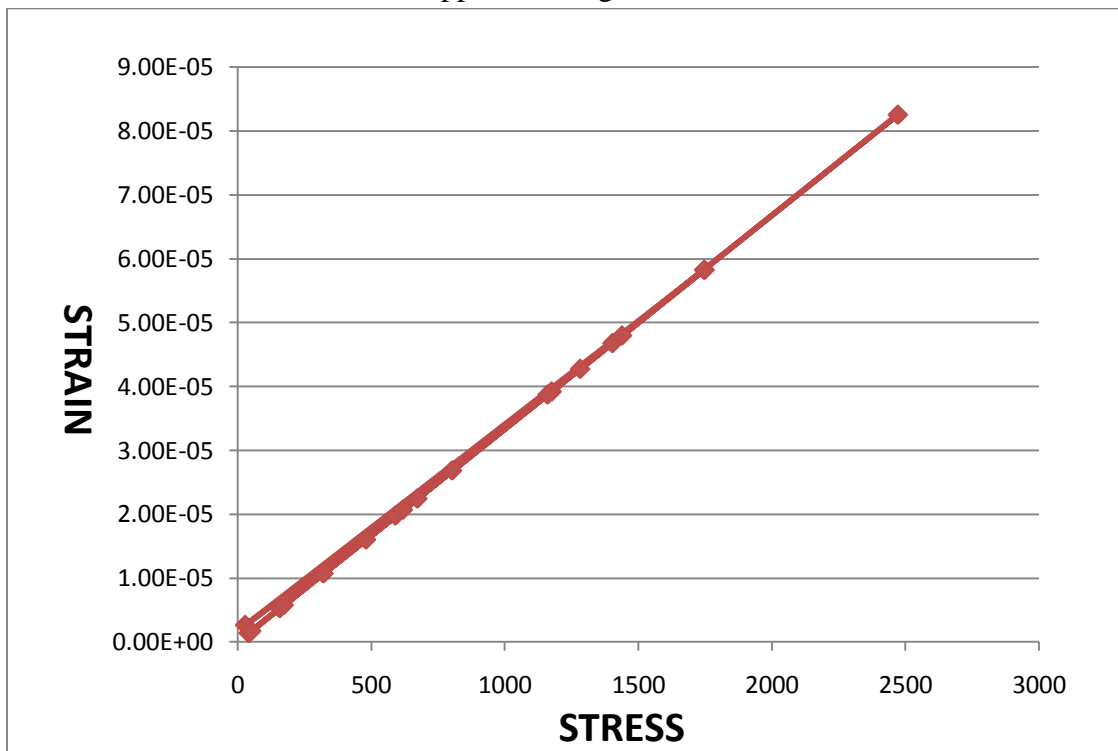


Stress-Strain relationship for 1000 N Load applied in the negative Z direction.

1) Scatter diagram for stress-strain curve for -1000N load



2) Stress-strain curve for 1000N load applied in Negative Z direction



Stress Analysis of Cantilever Beam with 3000N Force in Negative Z direction.

Total No of Nodes: 2936

Load Applied: Node 2585

Maximum Stress: Node 243

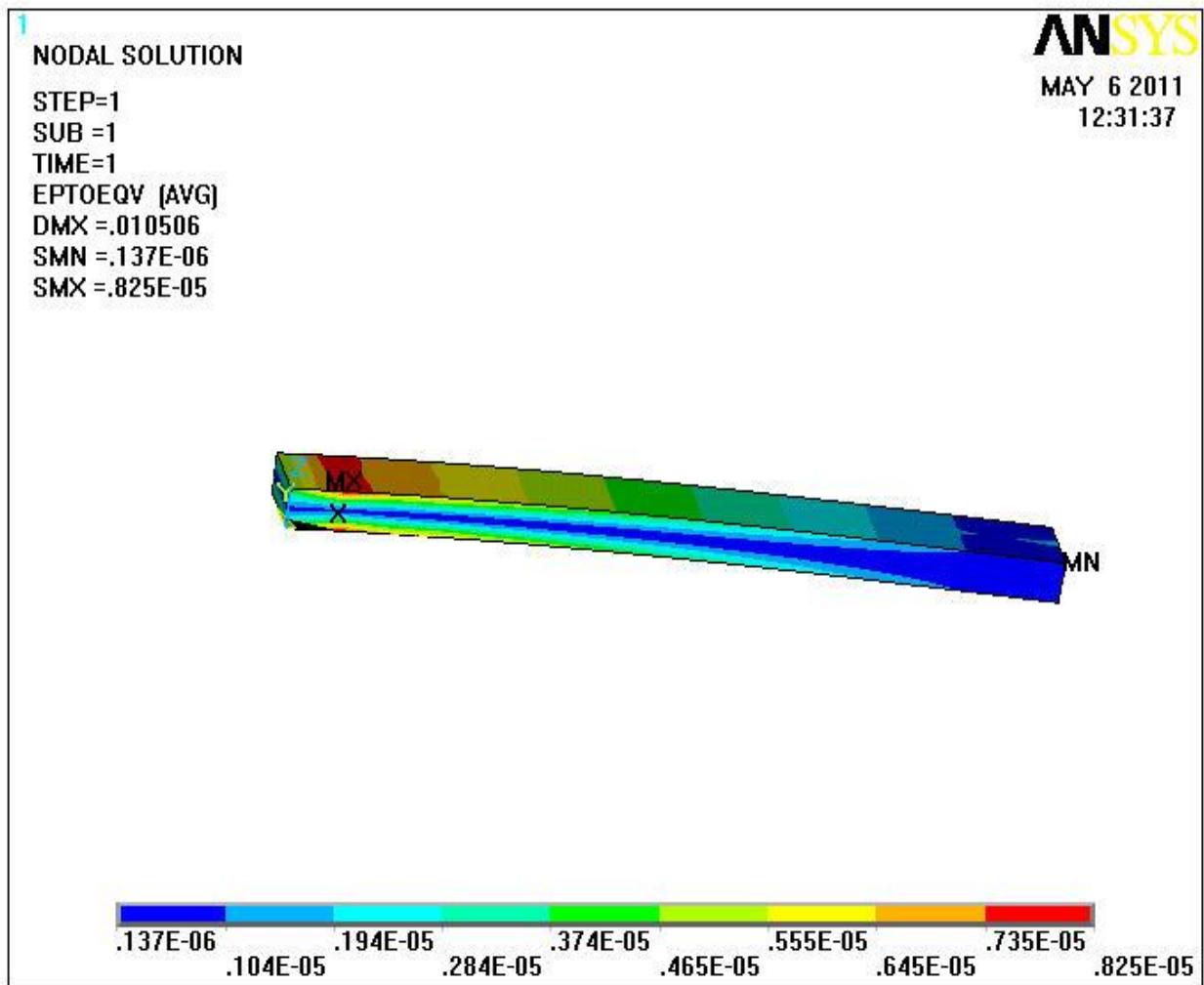
Minimum Stress: Node 1502

Maximum Stress: 7414.5 N/mm²

Maximum Strain: Node 243

Minimum Strain: Node 1290

Minimum Stress: 83.048



Strain Analysis of Cantilever Beam with 3000N Force in Negative Z direction.

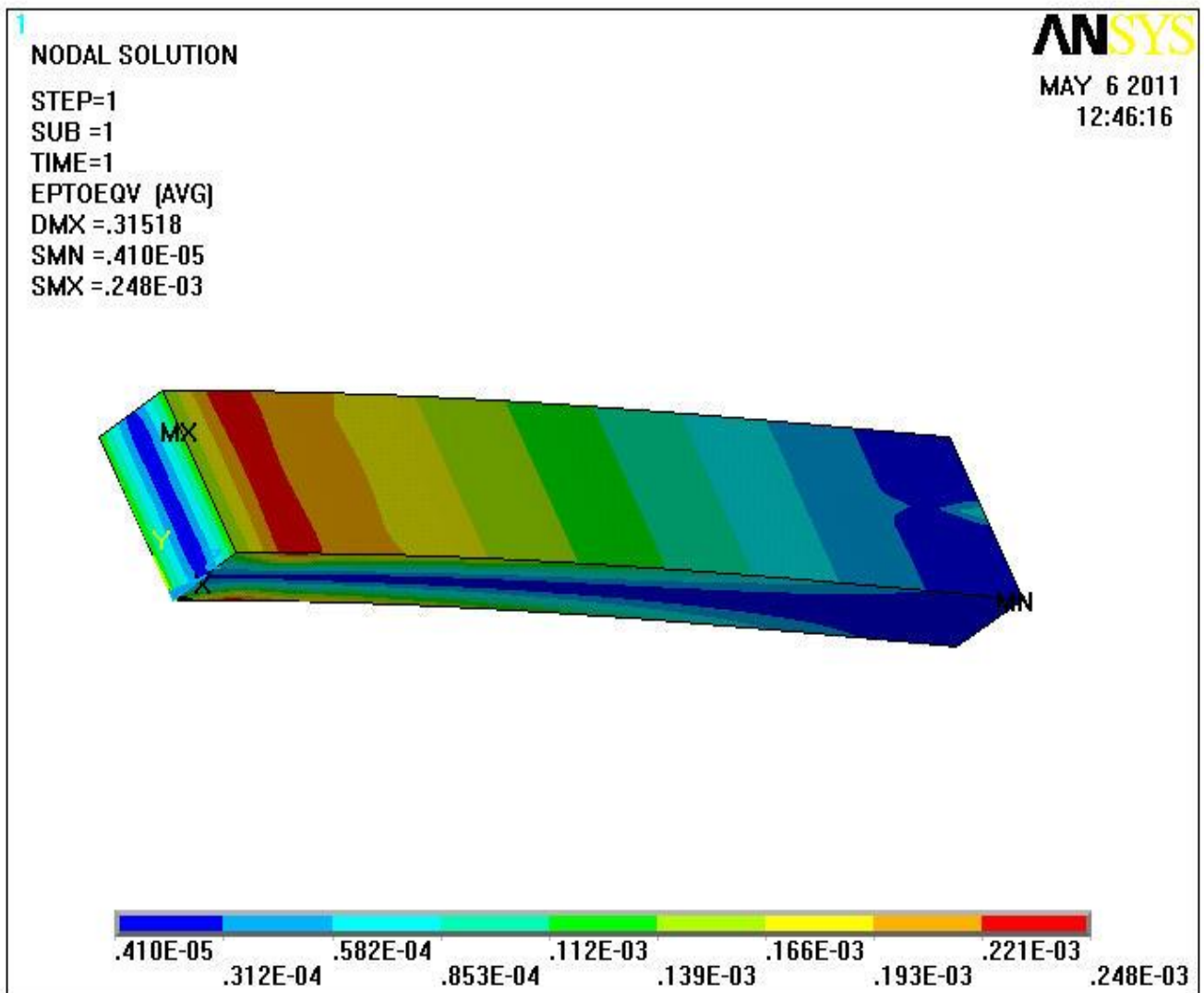
Maximum Strain Node: 243

Maximum Strain: $2.48\text{E-}04$

Minimum Strain Node: 1290

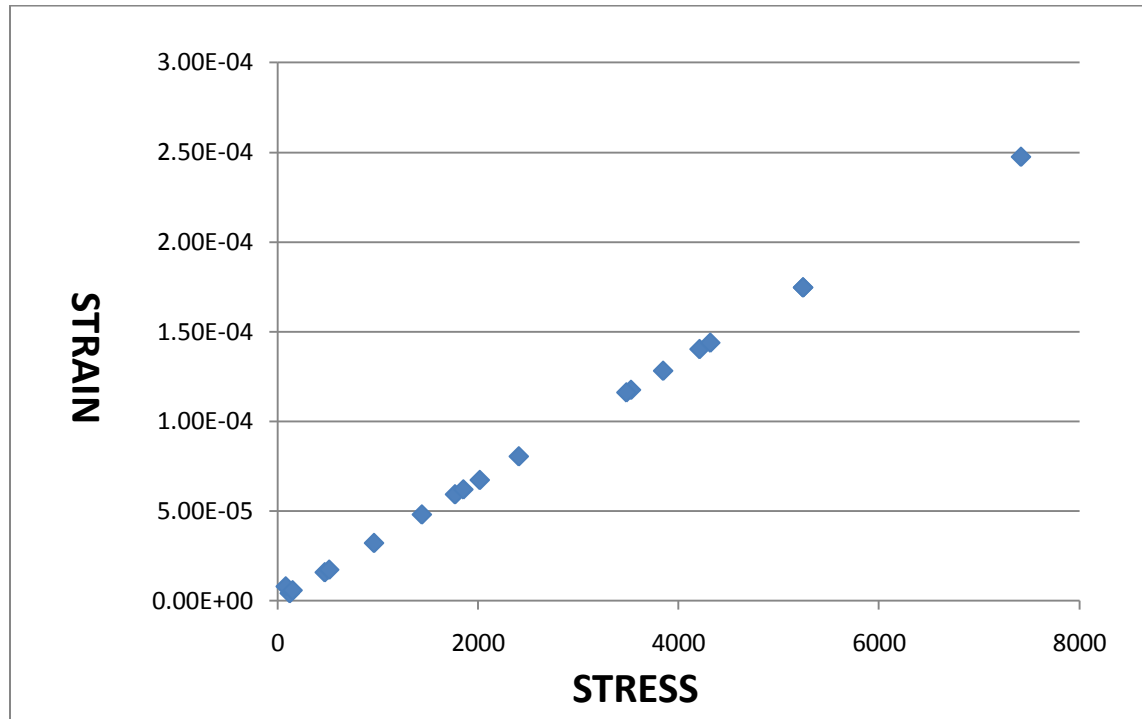
Minimum Strain: $4.10\text{E-}06$

As displacement and strain are directly proportional, maximum displacement occurs at the point of maximum strain. When higher load is applied, high displacement and hence high strain produced at the specific area of the beam.

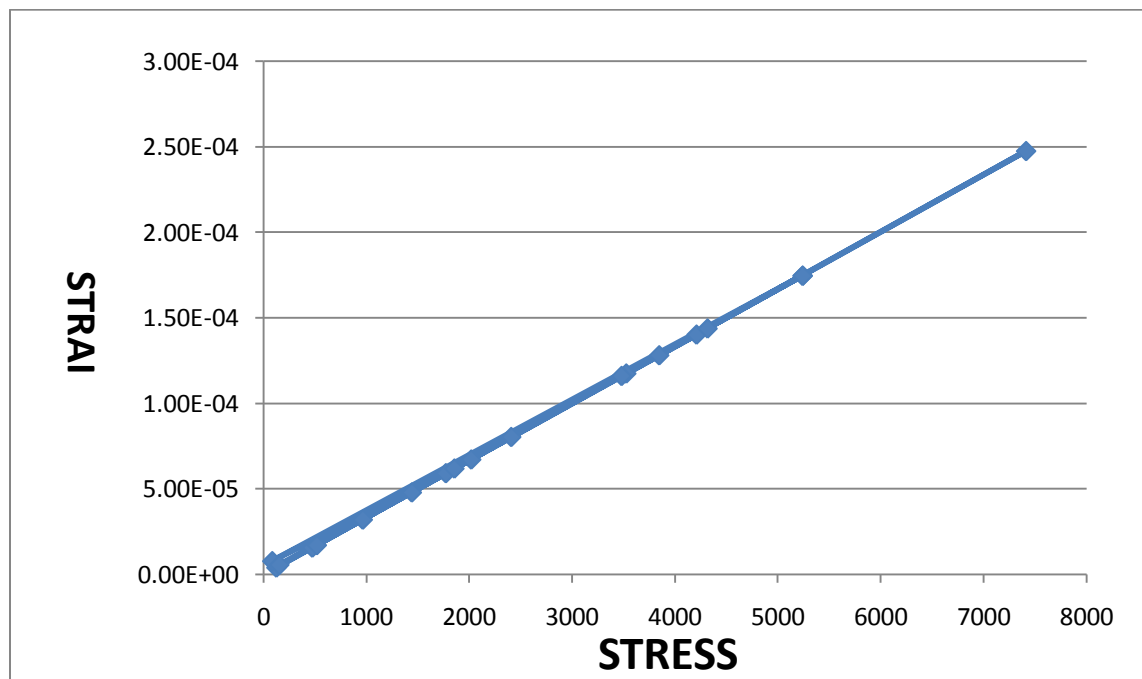


Stress-Strain relationship for 3000 N Load applied in the negative Z direction.

1. Scatter diagram for stress-strain curve for -3000N load



2. Stress-strain curve for -3000N load



Calculations:

As we know the Young's modulus is calculated as the ratio of stress to strain.

So as per the definition we have $Y = \text{Stress} / \text{Strain}$

For load 1 i.e. -10 N, from the stress v/s strain graph, we have,

$$Y = 31.25 \text{ TPa}$$

For load 2 i.e. -100N, from the stress v/s strain graph, we have

$$Y = 30.5 \text{ TPa}$$

For load 3 i.e. -1000N, from the stress v/s strain graph, we have

$$Y = 31.5 \text{ TPa}$$

For load 4 i.e. -3000N, from the stress v/s strain graph, we have

$$Y = 31.25 \text{ TPa}$$

So, taking average value from all the values for Young's modulus we have,

$Y(\text{avg})$ for this sandwich beam is **31.125 TPa**.

Conclusion:

Sandwich cross sections are composite and consist of a low to moderate stiffness core which is connected with two stiff exterior face-sheets and it has a considerably higher shear stiffness to weight ratio compared to an equivalent beam made of only the core material or the face sheet material. The face sheets that were used for this analysis were of PZT-5 material having a young's modulus of 63 GPa and the core material was of Aluminium which has a young's modulus of 69 GPa. When we analyzed a sandwich beam with core as aluminium and face sheet as PZT-5 material the young's modulus for the sandwich beam composite was found to be **31.125 TPa** (taking an average value from all the loads applied on a particular node). The value is acceptable as it is proved from early researches that the young's modulus for a sandwich beam is supposed to yield much better results compared to an equivalent beam made out from individual materials that are used as core or face sheets.

Scope for future work:

For the simplification purpose a three layered sandwich beam was selected and the core material for this purpose selected was aluminium and the face-sheets as PZT-5. There are few works that have been carried out in this direction where instead of 3 layers, more layers are being used and instead of simple layer like arrangements honeycomb like structures are used. Instead of core as aluminium and face-sheets as PZT-5 other materials showing considerable young's modulus value too can be used.

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